A First Reconstruction Algorithm for the Photon Detection System

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LBNE Simulation/Analysis Call
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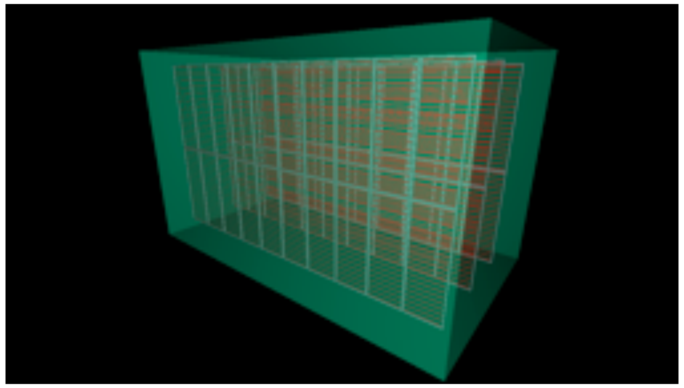
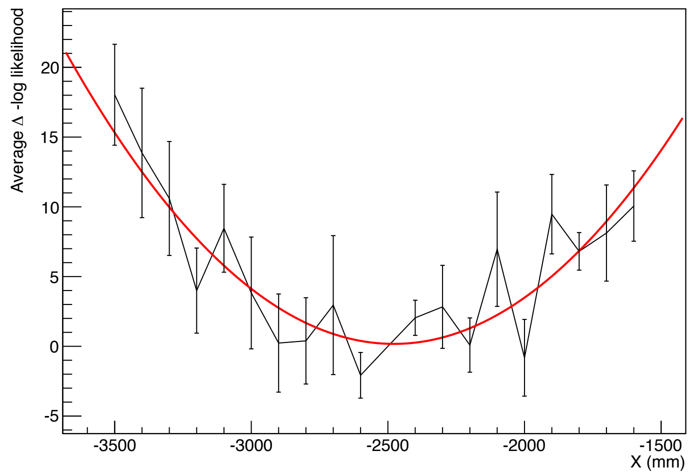
Previously...

- I showed an optical model of the 5 kton cryostat built in Chroma.
- Using Chroma, a likelihood could be calculated for a muon track hypothesis.
- Even accepting large variance in the likelihood estimate, this calculation was excruciatingly slow and impossible to use as a practical fitter (even in 2020).
- *Monte Carlo is painful because only one in 100,000 scintillation photons is actually detected!*





A *Practical* Likelihood Fitter

- If we ignore time, we can build a reasonably accurate likelihood function using the *number of photoelectrons* (PE) detected in each channel as our observables.
- Due to the narrow charge resolution of solid-state photon detectors (which are now the preferred option rather than traditional PMTs), the number of PE observed in each channel for a given hypothesis will be Poisson distributed.
- A Poisson distribution is parameterized by a single parameter (the mean # of PE), which we can estimate much more quickly than the shape of an arbitrary PDF (like the time PDF for each channel).

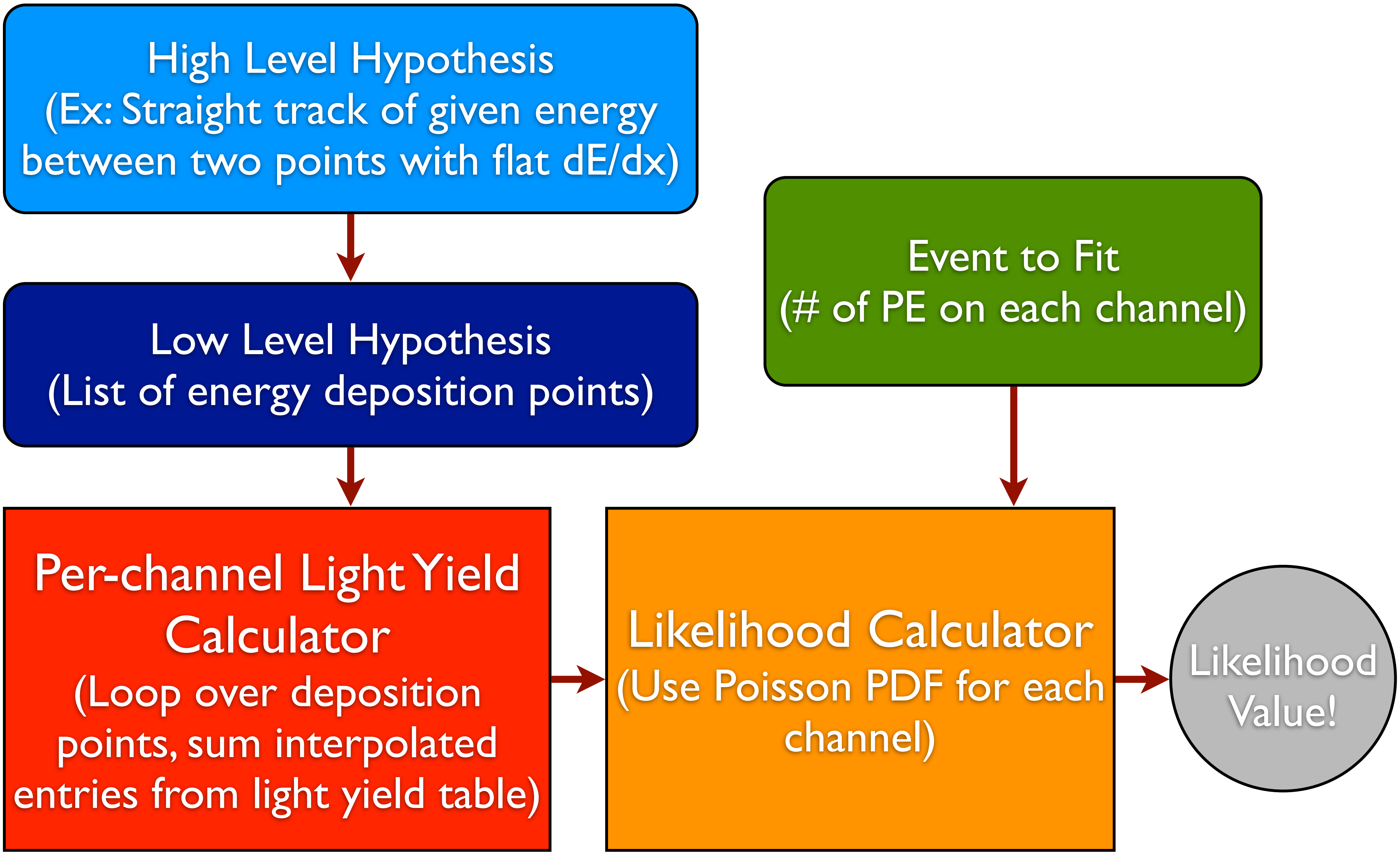
Table Lookup

- Scintillation light is isotropic and independent of the direction of the particle momentum vector, so we can reduce the optical response of the detector to a large lookup table.
- Y(x,y,z,i) = Light yield (PE/MeV) of channel i for energy deposition at position x,y,z in the detector.
- For a 1 meter grid, this table is only 56 MB. (Could be 28 MB if used single precision.)
- Generate the table by running the full Monte Carlo producing point sources of light at random locations in the detector, then averaging in ~1 meter bins.
- My current table is based on 2.4e12 UV photons propagated by 3 GPUs over the course of 2 weeks. (Probably overkill.)

Defining the Hypothesis

- What form should our event hypothesis take, and how should we parameterize it? (i.e. *What are we fitting for?*)
- The energy deposition in an event can be pretty complex so we want to decouple that choice of parameterization from the likelihood calculator.
- Choose a "low-level" hypothesis representation for the interface:
  - List of energy deposition points = [(E, x, y, z), ...]
  - Easy to compute the expected number of PE for each channel given such a list.
- A high-level hypothesis (like a muon track) can be decomposed into a list of energy deposition points.
- Could actually use energy deposition information from TPC to generate hypotheses for the photon likelihood fitter to test...

Evaluating the Likelihood



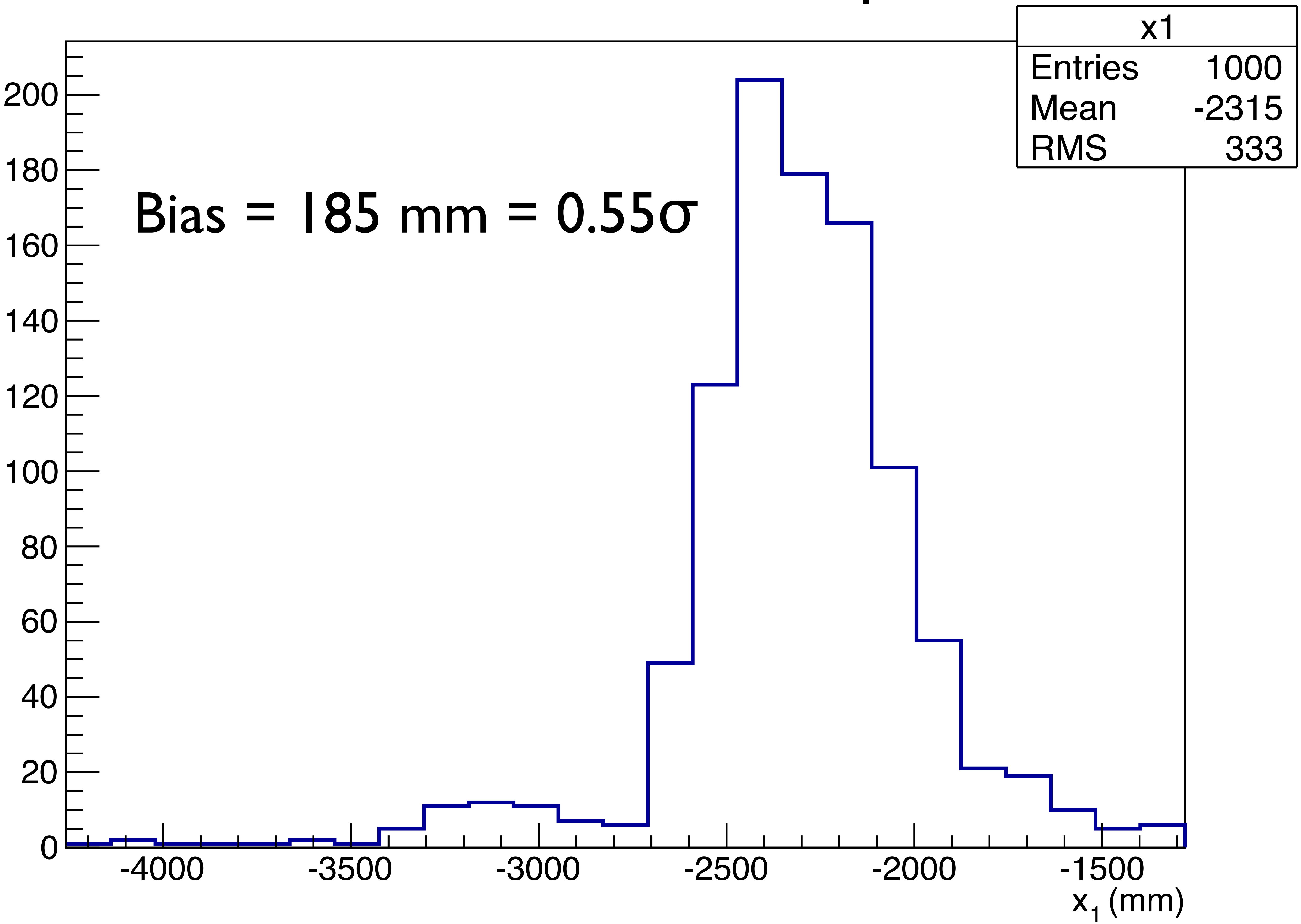
Making a Fitter

- Parameterized hypothesis + likelihood function + minimizer
  = reconstruction!
- Hypothesis: Straight track between two points, flat dE/dx (*not realistic*)
- Parameters: $(x_1, y_1, z_1), (x_2, y_2, z_2), E$
- Likelihood function: See previous slides. Track decomposed into energy depositions every 5 cm.
- Minimizer:
  - Estimate energy using total charge and average light yield of entire detector.
  - Grid scan in x,y,z in ~50 cm steps with a point-like hypothesis to find the centroid of energy deposition.
  - Fix centroid, extend out track and grid scan direction of track
  - With this seed, minimize all 7 parameters simultaneously using MINUIT gradient descent.

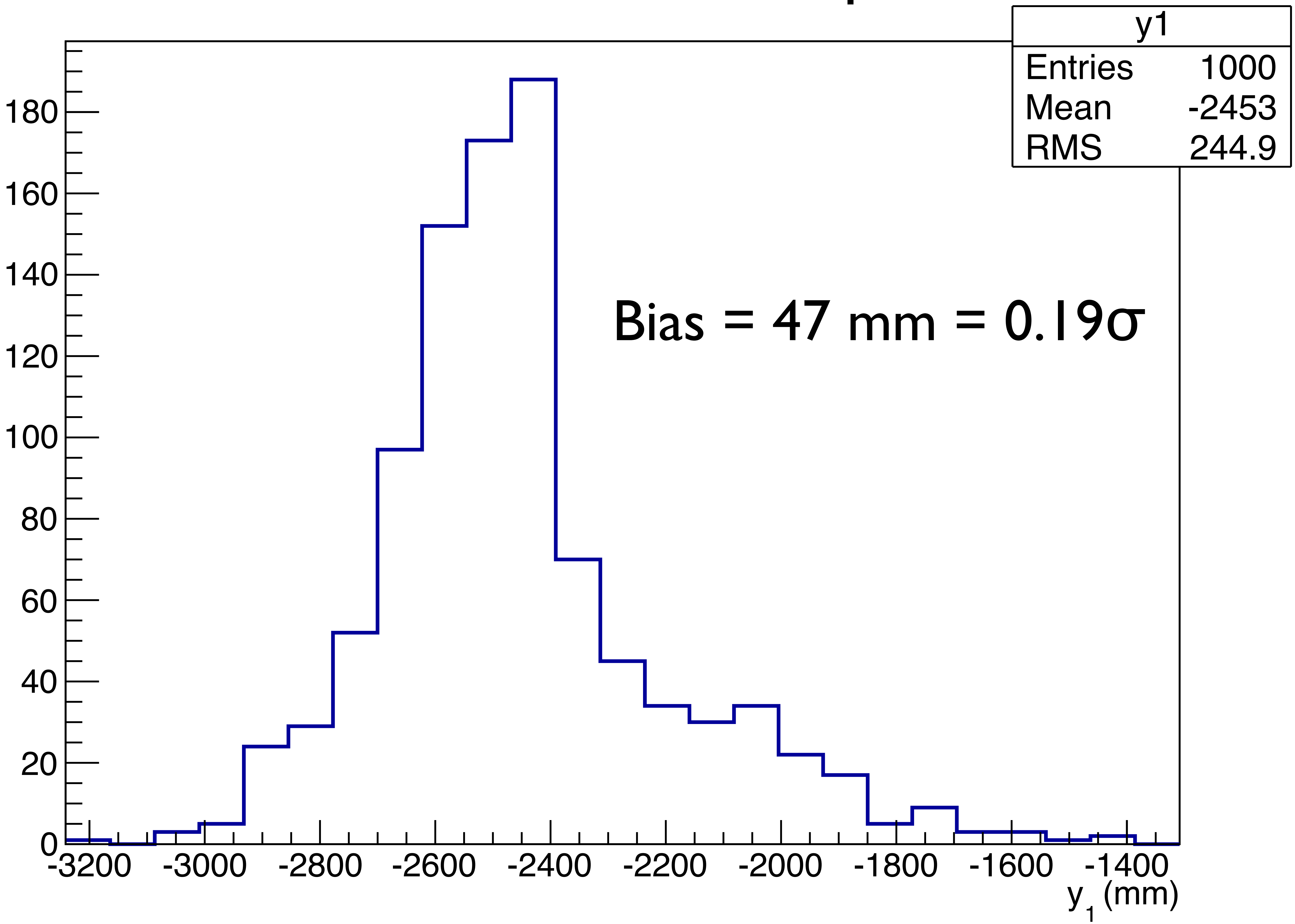
Fitter Test

- 1000 muon track-like events generated by full Chroma simulation:
  1 GeV, (-2.5m, -2.5m, 0.0m) to (-2.5m, -2.5m, -4.7m)
- Fit each event using the algorithm from the previous slide.
- Time per fit: 20-30 seconds

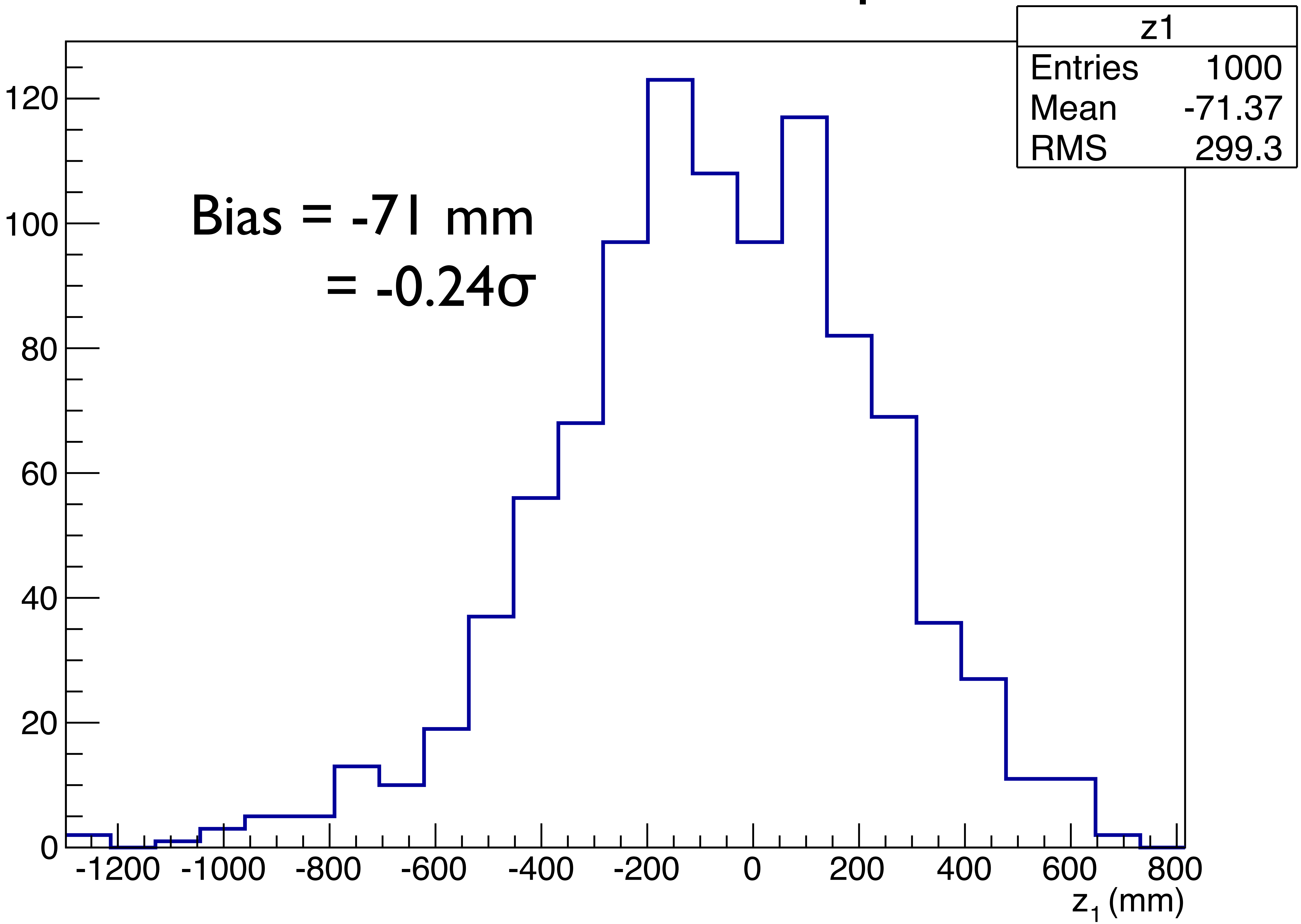
Parameter: X_1



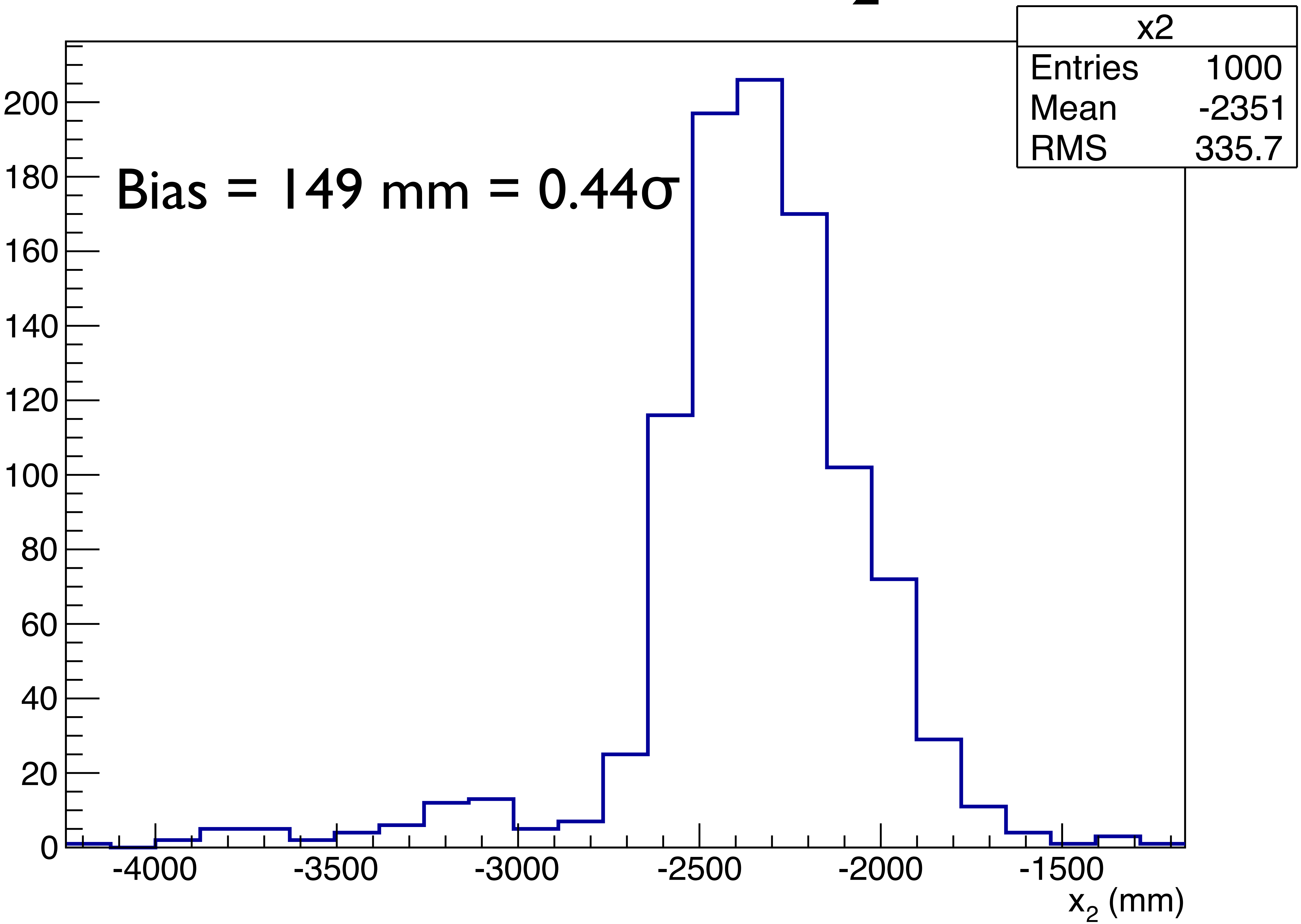
Parameter: Y_1



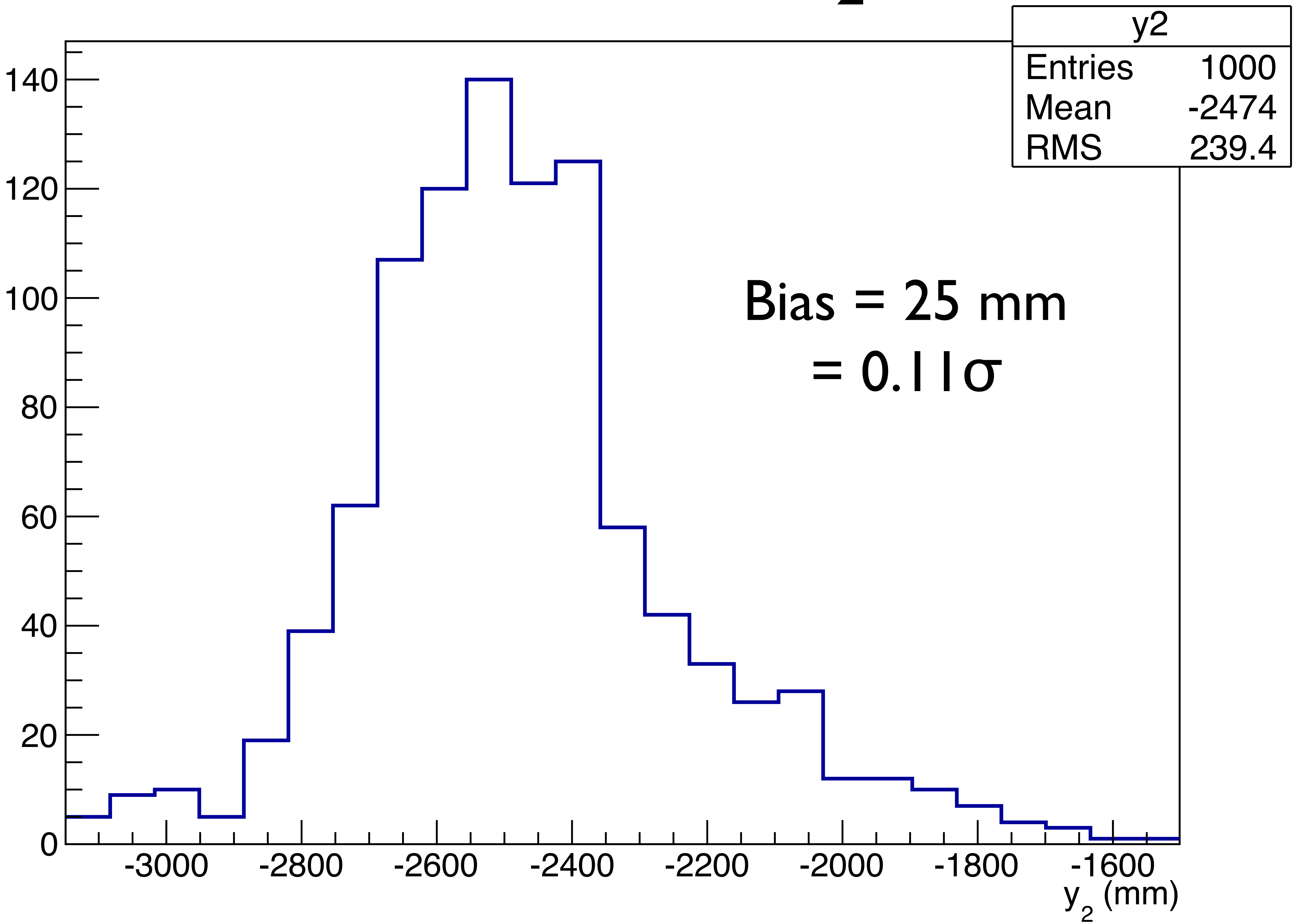
Parameter: Z_1



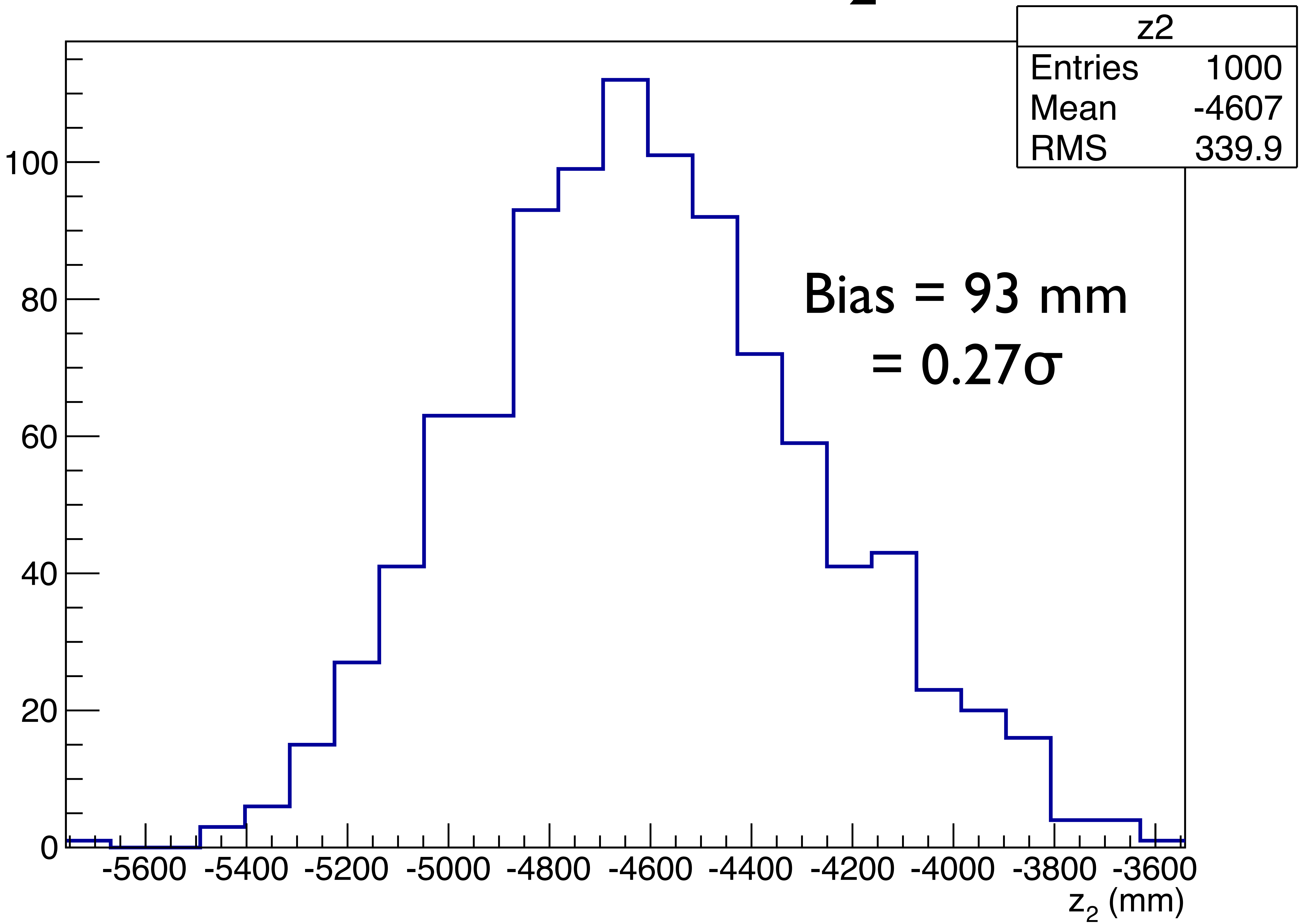
Parameter: X_2



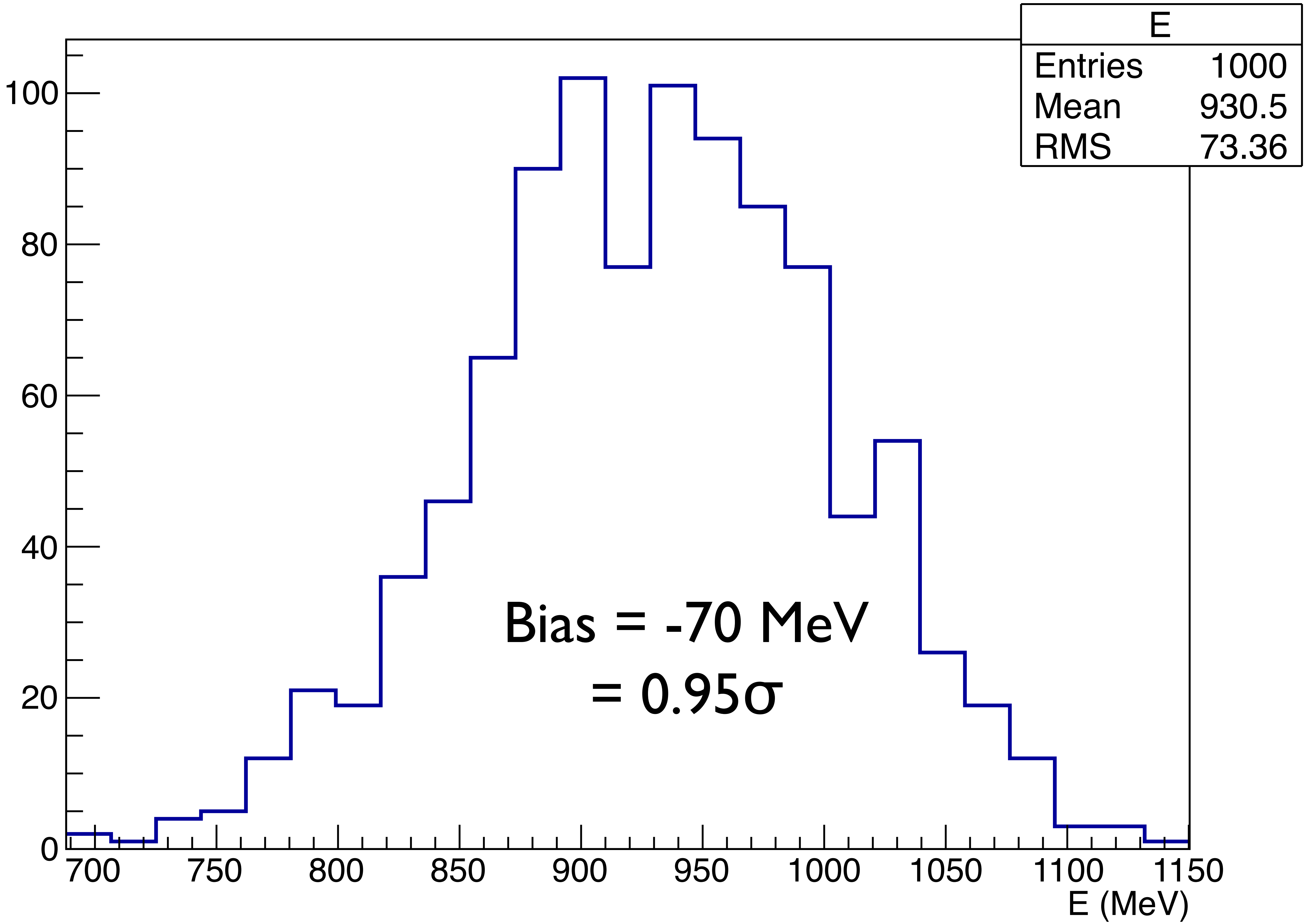
Parameter: Y_2



Parameter: Z_2



Parameter: E



E
Entries 1000
Mean 930.5
RMS 73.36
Bias = -70 MeV
= 0.95σ
0
20
40
60
80
100
700
750
800
850
900
950
1000
1050
1100
1150
E (MeV)

Note about MINUIT errors

- The likelihood spaces are at little choppy, so the MINUIT uncertainties tend to be too small.
- MINUIT uncertainties are generally between 1.1 and 1.5x smaller than RMS of actual fits.
- *Have to rely on distributions of many fit events to actually assess uncertainties for now.*

Conclusions

- *We have a working reconstruction algorithm for the LBNE photon system! First estimates of performance for a particular location:*
  - ➡ *Bias: < 2.5-19 cm in track position, 7% in energy*
  - ➡ *Resolution: 25-35 cm in track position, 7.5% in energy*
- After spending a week generating the light yield table, the fit itself is pretty fast: less than 30 seconds per fit.
- Near-term todo:
  - Regenerate light yield table for detector with *opaque* steel cathode planes.
  - Create a more realistic high-level hypothesis: muon tracks with a realistic dE/dx or electron showers? Some generic parameterized event?
  - Start studying the resolution performance as a function of steel reflectivity, attenuation length, TPB coverage, etc.